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EXPERIMENTAL INVESTIGATION OF SOLAR DRYER USING PHASE CHANGE MATERIAL

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ABSTRACT

The sun is the most important source of heat and light in the universe and also one of the major renewable sources. In many countries, they are utilizing solar energy in the agricultural area to preserve vegetables, fruits, other crops, and meat. Utilizing solar energy into useful work is our main project. Solar dryers are the devices that use solar energy to dry substances, especially food products. A similar investigation of a portion of the accessible solar dryers demonstrate that the solar dryer moderately decreases the drying time of item through the reasonable utilization of warmth stockpiling materials like rock bed, pebbles, sand, clay and so on. A phase change material (PCM) is a substance with a high heat of fusion which, is melting and solidifying at a certain temperature, is capable of storing and releasing large amounts of energy. The fundamental goal of the present exploratory examination is to build up a solar dryer as a method for nourishment drying, helped by the PCM, and to research the impact of PCM on warmth accessibility, heat use and drying energy of sustenance. Hence the experimental procedure was done to access the comparative study of natural convection solar dryer and the natural convection solar dryer using PCM, which is used to increase the drying rate of the product.

KEYWORDS: Solar Dryer, Phase Change Material & Natural Convection

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Original Article

INTRODUCTION

Drying is a mass transfer process consists of removal of water by evaporation from a solid, semisolid or liquid. Sustenance drying is a technique for the nourishment protection where nourishment is dried. In many developing countries large quantities of fruits and vegetables spoil due to inadequate infrastructure, insufficient processing capabilities, and growing marketing difficulties caused by the intensifying competition and protectionism in the worldwide agricultural markets. Analysts guarantee directly from 3000 to 5000 years prior horticulture was far-reaching in the Indian landmass. The all-out generation and financial estimation of plant products, for example, organic products, vegetables, and nuts have multiplied in India over the 10-year time frame [1,2]. In 2012, the total horticulture products reached 277.4 million metric tonnes and acquired a position as the second-largest producer of horticultural products. Indeed, even in types of winter oats like grain, oats, and wheat persistent with great generation. India in 2013 created 81 million tons of natural products, 162 million tons of vegetables, 5.7 million tons of flavours, 17 million tons of nuts and plantation products cashew, cacao, coconut and so forth. But we should keep in mind that India is a country where 70% of farmers cultivate monsoon rains [3,4]. So, failed monsoon for one of the world's biggest producers of horticulture and grains could add pressure on global food prices. This results in a high burden on the farmers mentally and economically. Activists and researchers have offered various clashing

explanations behind rancher suicides, for example, rainstorm disappointment, high obligation loads, hereditarily changed harvests and not coming to of government arrangements. Every year we spend crore's of rupees out of public exchequer for preventing decay and then spend a fortune again to dispose of the piled up waste[5,6]. This results in inflation on a particular crop. To overcome these problems preservation is needed, i.e., by removing the moisture content in food. So these high produced horticultural products are transformed to dry one to reach the demand for an increasing population, balances the demand at monsoon failures [7].

Solar dryers are classified according to the flow of air-natural convection and forced convection dryers. Forced convection dryers require a fan or a blower. Solar drying is also classified into direct, indirect and mixed-modes. In the direct solar dryers, the material is stored in the insulated box. Solar radiation passes through a transparent cover which is absorbed by the materials. In indirect dryers, heat energy contained in solar radiation is collected in a separate solar collector (air heater or heating chamber) and the hot air is directed to the drying chamber where the material is placed. While in the mixed-mode type of dryer, the hot air from the attached solar collector is flown over a material bed and simultaneously, the drying chamber absorbs heat energy from sunlight directly through the transparent walls or roof.[8] By different properties, phase-changing materials are named as organic, inorganic, and salt hydrates and so on. The utilization of sensible or latent heat exclusively relies upon the temperature range required for the procedure.[9] The sensible and latent heat storage is the key factor in the working of solar dryers. Heat consumed for phase change procedure is a type of extra heat storage in latent heat move when contrasted with the sensible heat move.[10,11]

Other than different parameters of drying, the temperature is the fundamental parameter which influences extensively the drying time frame and energy of drying. Temperature accessible for drying chooses the rate of drying in both the phases of drying energy; drying is a rate of diffusivity of dampness which relies upon accessible heat, and temperature shows the degree of heat content [12,13]. In this test, phase changing material was connected inside the drying chamber which possesses the side-wall territory of the drying chamber and fills in as a vitality storage material. Vitality storage materials are essentially separated into two sorts, one which is fit for sensible heat storage and another one fit for latent heat storage during phase change. Also, Phase changing material was utilized to ponder the impact of drying [14,15].

To evacuate moisture in direct and indirect mode, solar drying techniques are accessible. In direct strategy, the crop is straightforwardly presented to solar radiation. Be that as it may, on account of method technique, harvest is placed in a closed system and sun based radiation is consumed by some transparent surface – for the most part, a sunlight based authority where it is changed over into heat by refraction in the system. The current system of solar dryers exclusively takes a shot at accessible energy in the time just when daylight is accessible. Then again, working on solar dryers when daylights are low or not accessible is a noteworthy need to be researched [16, 17].

EXPERIMENTAL SETUP

Crops like cereals, grains, paddy, wheat, corn, and dry nuts have dry content in weight. So without proper removing of this moisture results in the growth of moulds, fungi and damage the grain quality results in the loss of crop. Harvest grain moisture content varies between 18 and 25% wet basis, if not dried quickly will reduce the quality of grain. Drying to reduce the moisture content to about 18% wet basis so that grain can be stored for longer, facilitate the milling process and to produce good quality grains. Similarly, in horticulture, crops like vegetables and fruits are facing large scarcity in production and preservation for the balance of a growing population.

Figure 1: Experimental Setup.

At less production and monsoon failure cases it results in inflation. Under these circumstances, the farmer is unable to produce the right crop at the right time. Though production is more at good rains farmer is unable to get a reasonable price. Mostly these crops are perishable crops i.e., lifetime or durability is very less. So, to get rid of this problem we have to store and protect the extra cultivation in various forms up to the next good monsoon. By this, we can control the scarcity of food as well as inflation. The experimental set-up used for the present study is designed and fabricated at G. Pulla Reddy Engineering College and located in Kurnool district. This experimental design consisted of heating and drying chamber. The design of the drying chamber was based on the volume required for 1.5 kg of vegetables. On basis of this volume the dimensions of dryer was 23 ×37 × 60 cm^3 with air passage (air vent) out of the cabinet of 90 × 10cm^2. The glass used as a cover for the collector was 83 × 60cm^2. The steel net was selected for the dryer trays to aid air circulation within the drying chamber. Three trays were made having wooden edges. The tray dimension is 21 × 50 cm of 2.5 cm × 2 cm wooden sticks used as a frame. In this proposed work, 5mm thick transparent glass was used. It also suggested that the metal sheet thickness should be of 0.4–0.5 mm thickness, here aluminium of 0.4 mm thickness was used. The glass used as a cover for the collector was 83 × 60cm^2. For the measurement of temperatures at various points thermocouples along with display panel were used. The drying chamber was connected to a heating chamber from which hot air for drying was made available. In the drying chamber, hot air removed the moisture from vegetables through evaporation. The weighing machine measured the loss in the weight of vegetables due to drying, which was observed manually after each hour.

SELECTION OF PHASE CHANGE MATERIAL

The organic phase change material (PCM) has several characteristics which render them useful for latent heat storage in certain building elements. These are more chemically stable than inorganic substances, non-corrosive, have higher latent heat per unit weight, recyclable, melt congruently and exhibit little or no supercooling, i.e., these do not need to be cooled below their freezing point to initiate crystallization. The maximum temperature at the inlet of the drying chamber was observed up to 55 °C. For experimentation, Lauric acid PCM was used. Characteristic properties of PCM are shown in Table 1. According to a box made for PCM storage, 1.5 kg of PCM box which covers 80% volume of the PCM box was used. As the box was placed on the bottom side of the drying chamber total of 1.5 kg of each PCM was used for experimentation.

Table 1: Properties of Lauric Acid

PCM	Melting Point(°C)	Thermal Conductivity (W/mk)	Boiling Point(°C)	Density (g/cm3)
Lauric acid	43.8	0.442	297.9	1.007

ARRANGEMENT OF CROP ON TRAYS

In the cabin, we have arranged the wire mesh trays at a distance of 10cm each vertically. Three trays were used with an average of 10 cm spacing arranged vertically one on top of the other, the tray size was 20 × 8.5 cm^2. Movement of air around produce ifurther facilitated by drying on mesh trays rather than on solid platforms. So, the aluminium net is stretched on wooden frames and supported by Kitchen wire. On these trays, we arranged the crop items in a quantity of 150 g as a test in this equipment. Slices of the crop with the thickness of 3mm placed on trays for the process of drying. So firstly we tried with the natural solar convention drying through cabin drying during the summer months, i.e., March, April, May, mid-June. The arrangement of the drying pictures can be seen in Figure 2.

Figure 2: Arrangement of the Crop at Trays.

RESULTS AND DISCUSSIONS

Firstly, we are showing the temperature variations and weight loss in the natural convection solar dryer, after that using PCM in natural convection solar dryer. These methods rely on measuring the mass of water in a known mass of the sample. The moisture content is set by measure the mass of food before and when the water is removed by evaporation.

$$\%\ of\ moisture = \frac{M(Initial) - M(dried)}{M(Initial)} \times 100$$

Here, $M_{Initial}$ and M_{Dried} are the mass of the sample before and after drying, respectively.

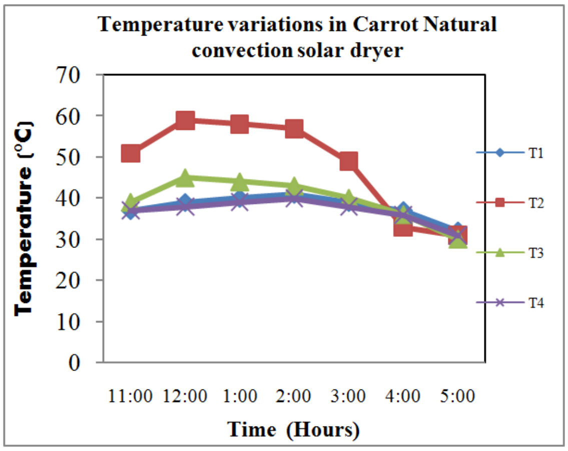
Temperature Variations in Natural Convection Solar Dryer (NCSD) for Carrot, Potato & Radish

Table 2: Temperature Variations in Carrot, Potato & Radish at NCSD

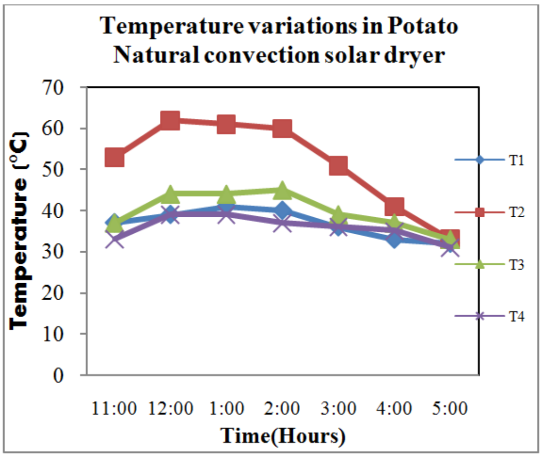
Time (Hours)	Heating Chamber Inlet			Middle of the Heating Chamber			Drying Chamber Inlet			Drying Chamber Outlet		
	T_1(°C)			T_2(°C)			T_3(°C)			T_4(°C)		
	Carrot	Potato	Radish	Carrot	Potato	Radish	Carrot	Potato	Radish	Carrot	Potato	Radish
11:00	37	37	36	51	53	59	39	37	43	37	33	37
12:00	39	39	37	59	62	61	45	44	45	38	39	38
1:00	40	41	38	58	61	63	44	44	46	39	39	40

Table 2: Contd.,

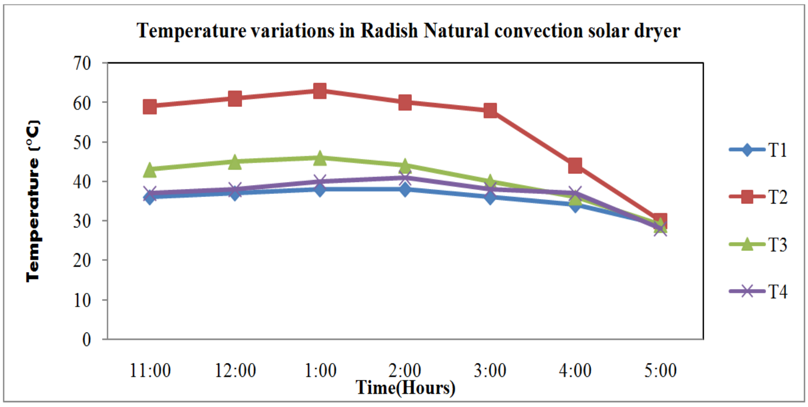
2:00	41	40	38	57	60	60	43	45	44	40	37	41
3:00	39	36	36	49	51	58	40	39	40	38	36	38
4:00	37	33	34	33	41	44	36	37	36	36	35	37
5:00	32	32	29	31	33	30	30	33	29	31	31	28



Graph 1: Time Vs Temperature for Carrot.



Graph 2: Time Vs Temperature for Potato.



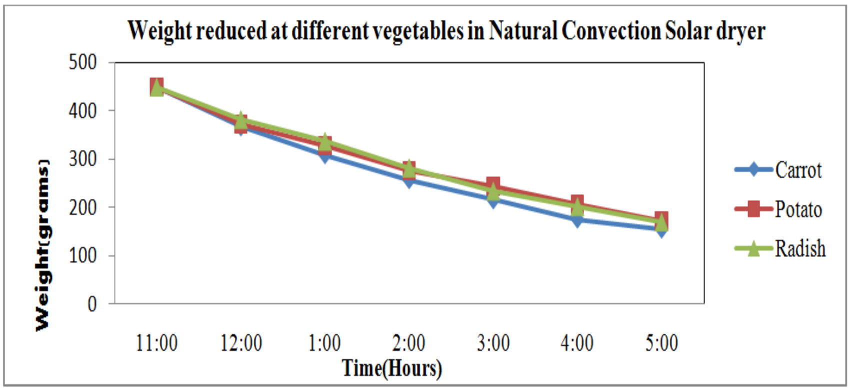
Graph 3: Time Vs Temperature for Radish.

Graphs 1–3 show temperature variations occurring at natural convection solar dryer from 11:00am to 5:00pm. In solar dryer four thermocouples are arranged in inlet and outlet positions. The maximum temperature occurs at 63°C at 01:00 pm.

Weight Reduction in all Vegetables using Natural Convection Solar Dryer

Table 3: All Vegetable Weight Loss

Time(Hours)	Carrot(g)	Potato(g)	Radish(g)
11:00	450	450	450
12:00	367	374	383
1:00	309	328	338
2:00	257	277	283
3:00	215	243	235
4:00	175	206	203
5:00	154	172	171



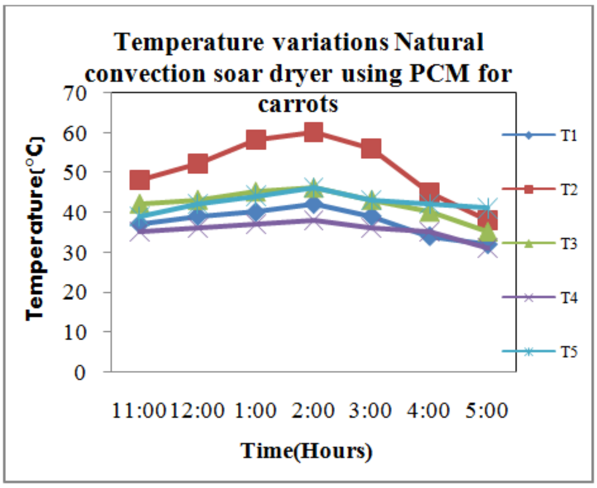
Graph 4: Time Vs Weight Loss at different Vegetables.

Graph 4 represents the variation between the time and the weight loss of all the vegetables (carrot, potato, radish). Each tray contains the weight of 150 g and it was arranged by a total of 3 trays. The total weight of each vegetable is 450 g. While starting at 11:00 am the weight is 450g. Weight was calculated for every one hour by using a weighing machine. At 5:00 pm the weight of each vegetable has reduced by naturally dried with the help of solar dryer.

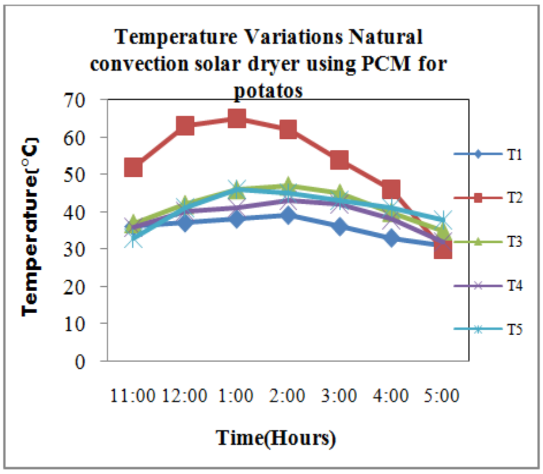
Temperature Variations in NCSD using PCM for Carrot, Potato & Radish

Table 4: Temperature Variations in Carrot using PCM

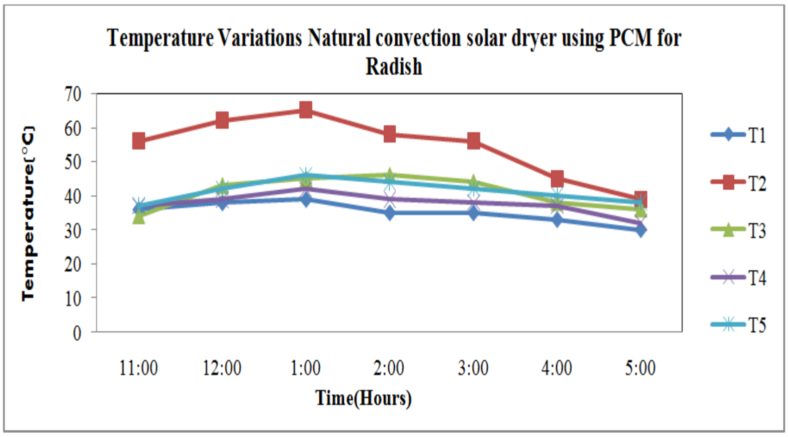
Time (Hours)	Heating Chamber Inlet T_1(°C)			Middle of the Heating Chamber T_2(°C)			Drying Chamber Inlet T_3(°C)			Drying Chamber Outlet T_4(°C)			PCM T_5(°C)		
	Carrot	Potato	Radish	Carrot	Potato	Radish	Carrot	Potato	Radish	Carrot	Potato	Radish	Carrot	Potato	Radish
11:00	37	36	36	48	52	56	42	37	34	35	36	37	39	33	37
12:00	39	37	38	52	63	62	43	42	43	36	40	39	42	41	42
1:00	40	38	39	58	65	65	45	46	45	37	41	42	44	46	46
2:00	42	39	35	60	62	58	46	47	46	38	43	39	46	45	44
3:00	39	36	35	56	54	56	43	45	44	36	42	38	43	43	42
4:00	34	33	33	45	46	45	40	40	38	35	38	37	42	41	40
5:00	32	31	30	38	30	39	35	35	36	31	32	32	41	38	38



Graph 5: Time Vs Temperature for Carrot using PCM.



Graph 6: Time Vs Temperature for Potato using PCM.



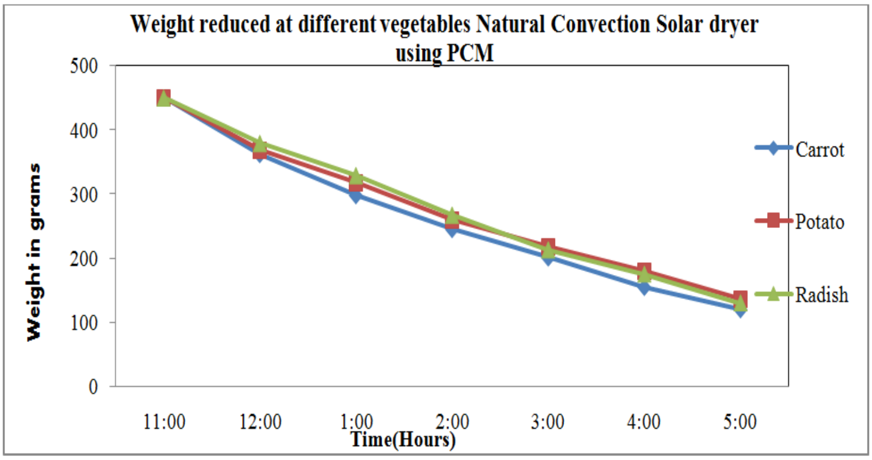
Graph 7: Time Vs Temperature for Radish using PCM.

Graphs 5–7 represent the variation between the time and the temperature variations occurred at natural convection solar dryer while using PCM. The maximum temperature has occurred at 65°C at 01:00 pm. The benefit of using PCM is it stores the energy while melting and released slowly. After 03:00 pm it was observed that the temperature falls down very slowly.

Weight Reduction at different Vegetables in NCSD with/without using PCM

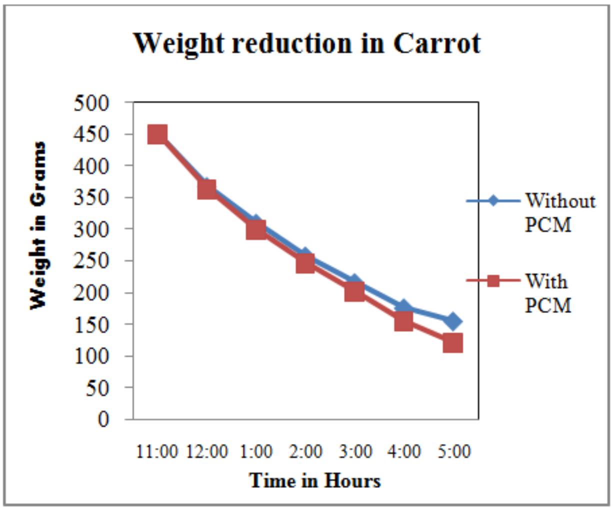
Table 5: Weight Reduction with/without using PCM at NCSD

Time (Hours)	Without PCM			With PCM		
	Carrot	Potato	Radish	Carrot	Potato	Radish
11:00	450	450	450	450	450	450
12:00	367	374	383	362	369	379
1:00	309	328	338	298	317	329
2:00	257	277	283	245	260	267
3:00	215	243	235	201	217	213
4:00	175	206	203	155	179	175
5:00	154	172	171	120	136	142

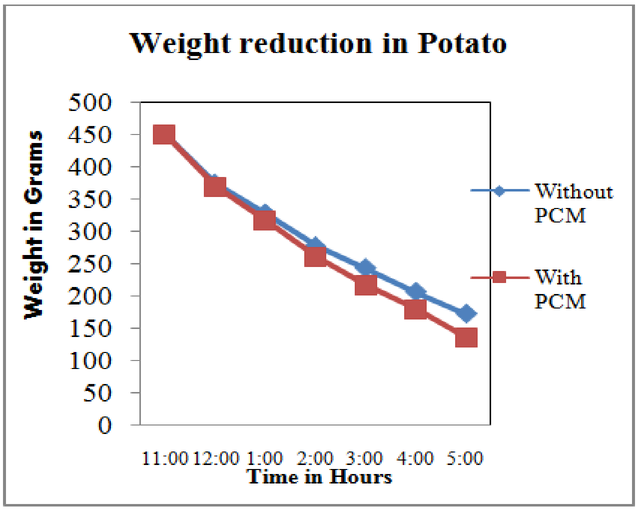


Graph 8: Time Vs Weight Loss at different Vegetables using PCM.

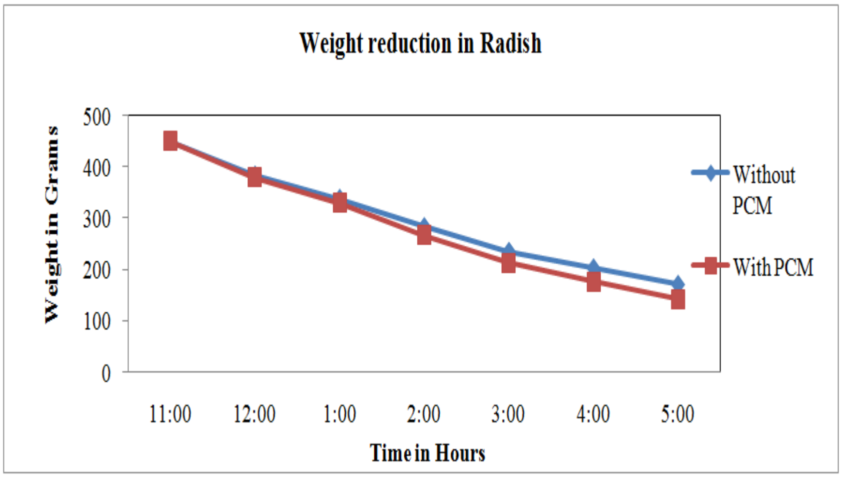
Weight Reduction using with & without PCM at Different Vegetables in NCSD



Graph 9: Time Vs Weight Loss in Carrot.



Graph 10: Time Vs Weight Loss in Potato.



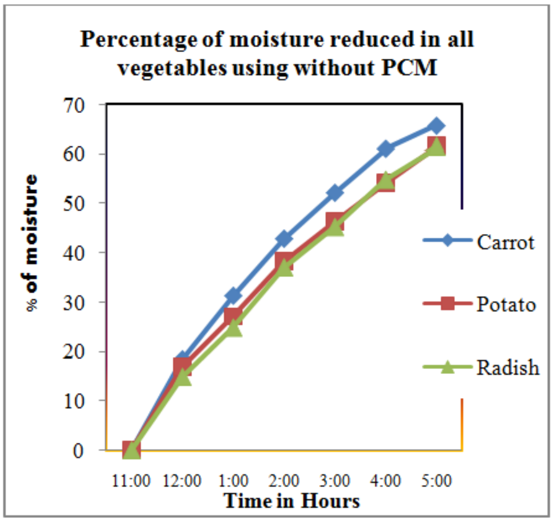
Graph 11: Time Vs Weight loss in Radish.

Graphs 9–11 represent the variation of weight has reduced with related to the time. Clearly, it shows that after 03:00 pm the weight has gradually decreased while using PCM as compared to without using PCM.

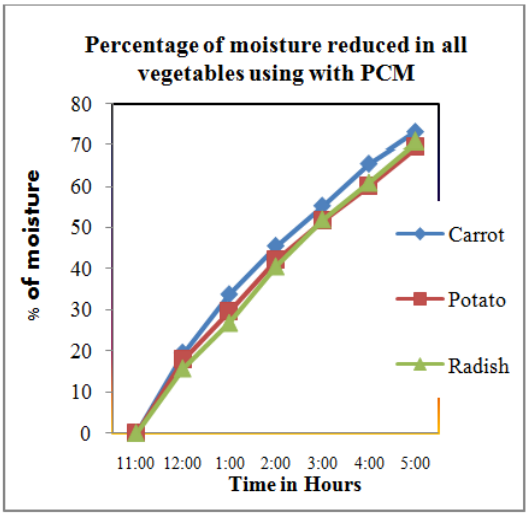
Percentage of Moisture Reduction using with & without PCM at different Vegetables in NCSD

Table 6: Reduced Moisture Values for all Vegetables with & without PCM

Time (Hours)	Without PCM			With PCM		
	Carrot	Potato	Radish	Carrot	Potato	Radish
11:00	0	0	0	0	0	0
12:00	18.44	16.89	14.89	19.56	18	15.78
1:00	31.33	27.11	24.89	33.78	29.56	26.89
2:00	42.88	38.44	37.11	45.56	42.22	40.67
3:00	52.2	46.28	45.32	55.33	51.77	52.12
4:00	61.12	54.22	54.89	65.56	60.22	61.11
5:00	65.78	61.78	61.56	73.33	69.78	71.11

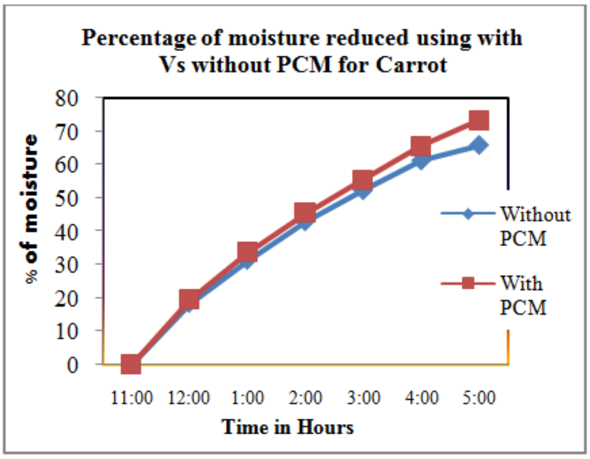


Graph 12: Percentage of moisture reduced without PCM.

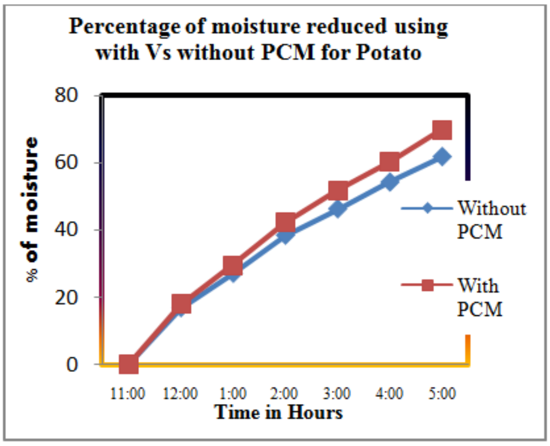


Graph 13: Percentage of moisture reduced with PCM.

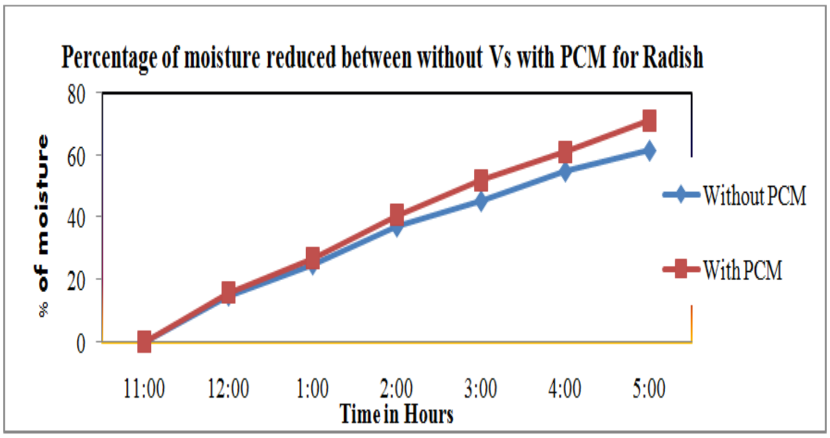
Graphs 12 and 13 represent the percentage of moisture decreasing while using with and without PCM at all vegetables in NCSD. It was observed that after 05:00 pm maximum moisture content has reduced by 73.33%.



Graph 14: Percentage of moisture reduced with and without PCM for Carrot.



Graph 15: Percentage of moisture reduced with and without PCM for Potato.



Graph 16: Percentage of Moisture reduced without and PCM for Radish.

Graphs 14–16 represent the variation between the time and the percentage of moisture reduced at every vegetable while using with and without PCM. It was observed that using PCM the moisture content has increased rather than the natural convection solar dryer.

CONCLUSIONS

- It can be concluded that the drying time is decreased and also the percentage of moisture decreased by using a solar dryer and solar dryer using PCM. After the early afternoon hours, roughly 03:00 pm onwards, the temperature fell at a quicker rate in a solar dryer, by utilizing PCM, this rate of temperature falls was less. So, the diminishing of drying time and the lessening in the level of dampness is more in solar dryer utilizing PCM when contrasted with the solar dryer. The percentage in decreasing the moisture content in the solar dryer using PCM is 8–10% more than the solar dryer. In the solar dryer, the weight reduced up to 290 g whereas 335g in the solar dryer using phase chase material.
- An experiment was carried out successfully for vegetable crop drying is achieved more temperature at the optimized conditions.
- 64.5% of weight reduction and 63% of moisture content has removed in natural convection solar dryer.
- 75% of weight reduction and 72% of moisture content reduction in natural convection solar dryer using PCM.
- Using PCM is an incredible alternative to upgrade the harvest drying rate.

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